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Impact of daylight quality on architectural space dynamics Case study: City Mall – Amman, Jordan☆

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ABSTRACT

This paper investigates the impact of daylight quality on the dynamics of architectural space. Observation of visual daylight aspects is photographically recorded in the main atrium of City Mall (CM), as an architectural space adopting daylight strategy. Classified photos explore the effects of daylight quality aspects on the dynamics of architectural space. Questionnaire is designed in-relation to the classified photos, and is subjectively assessed by a selected group of architects. Statistical analysis of questionnaire findings agrees that daylight quality affects the dynamics of architectural space, and could be an efficient design element for increasing esthetical and emotional aspects of architectural space. Measurements show dynamic daylight variations at different locations in the atrium and sufficient quantities for atrium activities. The study concludes that daylight quality can activate the dynamics of architectural space through adopting comprehensive daylight design to elaborate and advance dynamic visual daylight aspects, while providing required daylight quantities.

Contents

1. Introduction

Although there is no international agreement concerning daylight quality definition [1]; some literatures refer to daylight quality as the esthetic and emotional aspects of daylight, and that the perception of these qualitative aspects of daylight could not be indicated by numbers [2].

Therefore, in-accordance to research purposes; this paper adopts the definition of daylight quality as the esthetic and psychological aspects of daylight, which could be seen or felt subjectively

☆ This research is adopted of M.Sc. thesis in architectural engineering [18].

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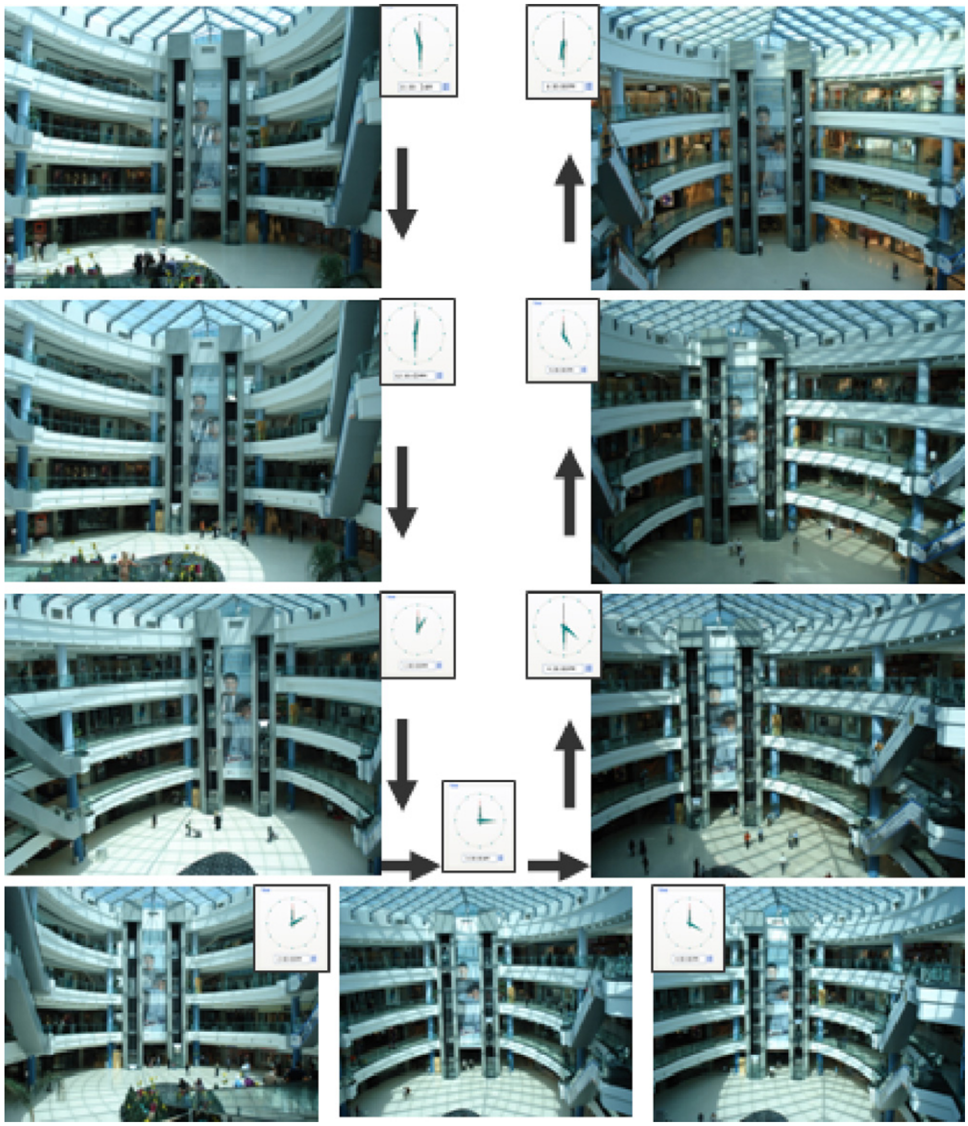


Fig. 1. Dynamic shadows rhythm during daytime in the main atrium of City Mall.

without numerical measurements due to daylight integration within architectural space elements.

When daylight was the only available method for illuminating buildings, realizing daylight quality in architectural spaces came out as accumulative result of designers' and architects' experiences, but without clear guidelines of how would the designed image of a daylight illuminated space meet the real appearance of architectural space.

The designers' sense and experience of revealing dynamic characteristics of the daylight architectural space has drawn back after the industrial revolution. Architects became less concerned about daylight entry to inner spaces of buildings due to the great development of electrical lighting and the availability of wide range of lighting fixtures. As a result daylight became less used, and even if introduced it followed the same mathematical approach usually used to estimate required daylight quantities of electrical lighting design.

Despite renewal concerns of daylight benefits associated with increasing trend of sustainable architecture and recent progression witnessed in architectural design toward adopting daylight for buildings illumination, architects and designers are still concentrating on availability of daylight quantities for specific activity, but missing qualitative daylight design for enriching architectural space, which raises the need for investigating the impact of daylight quality on the dynamics of architectural space.

2. Daylight quality benefits

Daylight benefits catalyze the adoption of daylight in architectural design. Visual comfort and psychological comfort are considered as daylight benefits that help actualization of other daylight benefits. Daylight quality is described as daylight that provides visual comfort for performing visual tasks with no glare, or as good distributed daylight that allows physical and psychological healing environments and daylight that gives sense of pleasure in the architectural space [3].

This paper presents daylight benefits concentrating on daylight quality studies, which had investigated the effects of visual diversity of daylight quality on providing visual and psychological comfort for improving productivity and human performance in the architectural space.

An earlier study conclude that visual comfort is related to luminance variability and visual diversity when the evaluation of 3 day lighted libraries in Cambridge showed that occupants prefer



Fig. 2. Atrium decoration and interrelation due to dynamic shadows rhythm.

luminance variability and visual diversity, where they would accept avoiding glare by only having the chance to change their sitting places to keep their preference enjoyment of the natural view out [2].

In addition, the visual comfort was evaluated in the cafeteria of the School of Architecture in Laval University, which had illustrated the importance of luminance diversity in the architectural space for providing visual comfort and various luminous choices for each specific activity [4].

The impact of visual comfort on occupants' psychological and emotional satisfaction at daylight work environment was investigated at EOS office building, Lausanne, Switzerland. The results confirmed that the most important daylight elements are good lighting, window and view out; and showed the most preferred elements for emotional satisfaction are window size and view out [5]. This means that the visual comfort due to daylight has positive emotional effects that increases employees' productivity and decreases their absence [6].

Also, additional studies in Hospitals had investigated the impact of daylight on patients' recovery, whereas 60% of patients in rooms with high indoor daylight levels were hospitalized for shorter periods than patients hospitalized in rooms with low daylight levels [7].

Other studies investigated impacts of daylight on students' health, emotions, attendance and performance. A 2 year study in U.S. elementary schools cleared more attendance by 3.6% for students in daylight classes than students in other classes depend mainly on electrical lighting and minimum day-lighting [8]. Another study in U.S. schools investigated the impact of daylight on students' performance through scores' analysis for over (21,000) students. Whereas students in the most daylight classrooms showed progress 20% faster on math tests and 26% on reading tests within 1 year than students in classes depending on electrical lighting with minimum daylight [9,10].

A study investigated the positive effects of skylighting on retail sales through sales reports analysis of 108 stores in the U.S. belonging to one trading company with similar design and management except that 2/3 of the stores depend on daylight illumination through skylights while 1/3 of stores depend on electrical lighting. The study cleared the increase of retail sales in daylight stores and expected increasing the retail sales due to implementing skylights to all company stores by 40% [11].

There is passed evidence that the absence of windows decreases the rental value of properties due to the preference of daylight properties [6].

Dynamic daylight quality gives architectural space more activity and spaciousness combined with the sense of joy and pleasure [12–14].

Actualization of daylight benefits is related to daylight quality in buildings.

3. Architectural space dynamics

Daylight reveals the shape of space and gives the space its dynamic characteristics [2]. Also, daylight differences and its diverse visual aspects create variant illuminance atmospheres in the architectural space [4], and dynamic daylight prevents dullness and stillness of architectural space, and gives a special character for the shape of space. Illuminated appearance of architectural space should be designed through effects of light or the reflected daylight seen by the eye (luminance) and not the illuminance which is not seen by the eye [15].

Revising daylight quality literature and according to the purposes of this study the architectural space dynamics is defined as the active motive effects due to variations of architectural space shape including dimensions, colors and appearance, which is caused by continuous differences of visual daylight aspects during daytime or from day to day through months and seasons over the year.

The architectural space dynamics owed to visual aspects of daylight quality are:

- Spaciousness of architectural space dimensions is related to dynamic reflections of internal specular surfaces of architectural space [15]. Luminance brightness ratio differences of dynamic daylight reflections thrown back from internal surfaces depending on their location within the space affect the spaciousness and sense of depth, such as vast luminance brightness differences

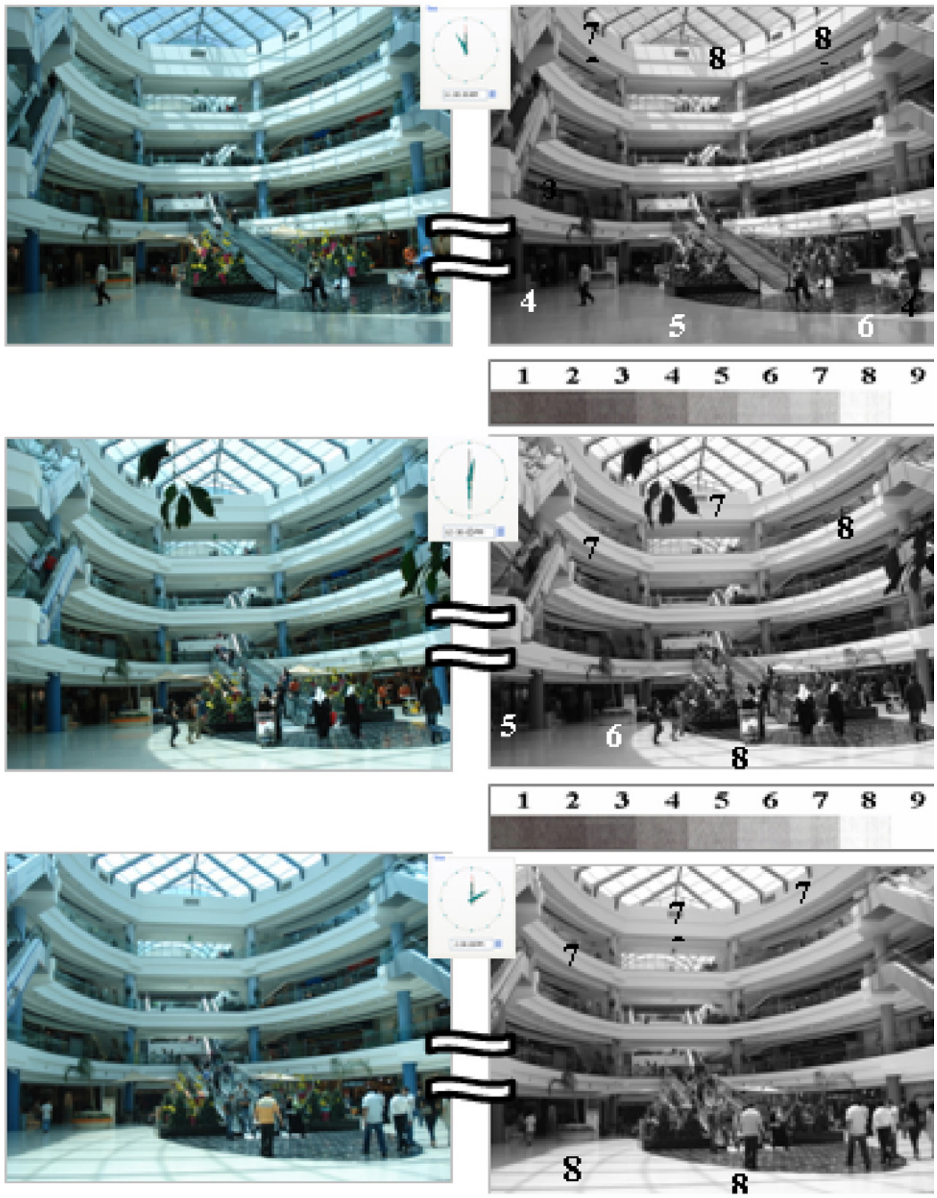


Fig. 3. Luminance brightness ratio differences in the atrium during daytime.

of fore and rear space would increase the sense of architectural space depth [16].

- Color diversity is related to luminance brightness differences due to continuous daylight variances, or to luminance brightness differences between shaded and lighted areas within the dynamic shadows rhythm and to luminance brightness differences of dynamic reflections.
- Continuous changing of appearance and renewal scene of architectural space is owed to dynamic shadows rhythm, which also defines the surfaces, depth and shape of architectural space while following the space perspective lines.

4. Procedure and tools

Observation, questionnaire and daylight measurements are used to investigate the impact of daylight quality variances on the dynamics of architectural space. "City Mall" in Amman, Jordan as a case study adopting daylight illumination strategy is selected to allow apparent and direct problem investigation.

Observation of dynamic visual daylight aspects of daylight quality is photographically recorded in the atrium and classified to explore the dynamic effects on the architectural space. A questionnaire is designed according to the classified photos to assess the impact of daylight quality and its dynamic effects on the architectural space. Daylight quantity is also investigated by measuring illuminance in the case study and comparing it to recommended lighting design manuals.

4.1. Observation

Observation of dynamic daylight aspects and its visual effects in the main atrium of "City Mall" is photographically recorded on 4/21, 4/25, 5/5, 5/18, 7/12, 7/13 and 7/19 of 2009, with an average of 3 h for each time to cover daytime working hours for a day of spring and another day of summer. The same part of atrium is photographed at intervals of half an hour to 1 h, and the whole scene of atrium is also photographed by a number of photos at a specific time. Observed photos are classified to explore the aspects of daylight



Fig. 4. Dynamic reflections in the main atrium of City Mall.

quality in order to assess its dynamic impacts on the architectural space.

4.2. Questionnaire

The questionnaire is designed in relation to the observed classified photos of visual daylight quality aspects in the case study. The questionnaire accompanied with a slide show of the observed classified photos is subjectively assessed by a selected group of 4th year students of architecture at Jordan University, as they have already passed most of the courses that qualify them to practice architectural design. The impact of daylight quality on the architectural space is analyzed through statistical analysis of questionnaires' data.

4.3. Daylight measurements

The study is extended to investigate how daylight design provides required illuminance for atrium activities according to lighting design manuals, while responding to desired dynamic daylight quality effects on the architectural space. Daylight illuminance is measured by a digital lux-meter in the main atrium of "City Mall" at the points of a grid every 1.8 m and a height of 0.8 m above floor level. Daylight readings were recorded on the 26th of August 2009 from 5:00 to 6:00 pm. External illuminance was also measured next to the north entrance at 0.8 m above floor level.

5. Results and discussion

Results of the impact of daylight quality on the dynamics of main atrium in CM are presented according to the examining tools.

5.1. Observation results and discussion

Observed photos are classified according to visual daylight aspects in the CM atrium to assess its dynamic impact on realizing and exploring apparent variety of architectural space concerning renewal of shape, diversity of colors and extended space dimensions.

5.1.1. Dynamic shadows rhythm

Repetition of photo shots for the same view of the atrium at intervals ranges from half an hour to 1 h have shown the changes and modification of architectural scene responding to dynamic rhythm of shadow shapes as shown in Fig. 1. Dynamic shadows

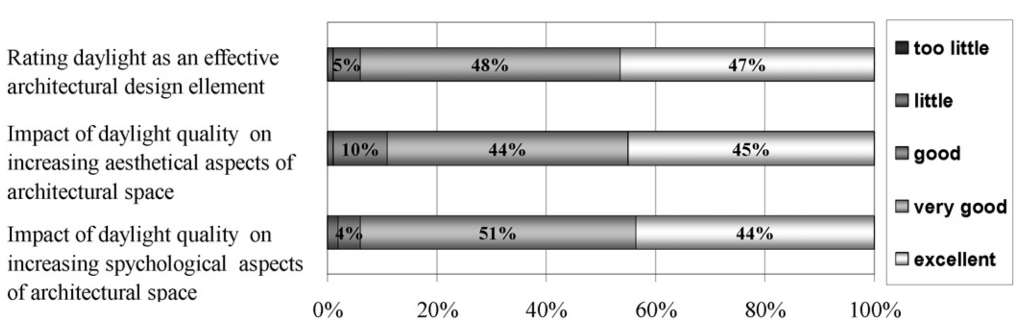


Fig. 5. Rating daylight as a design element for the architectural space.

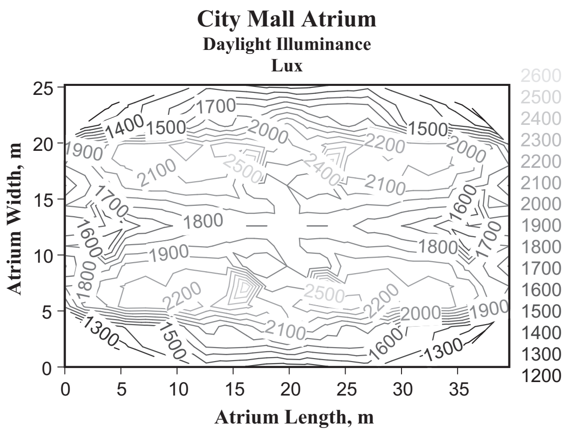


Fig. 6. Measured daylight illuminance in main atrium of CM.

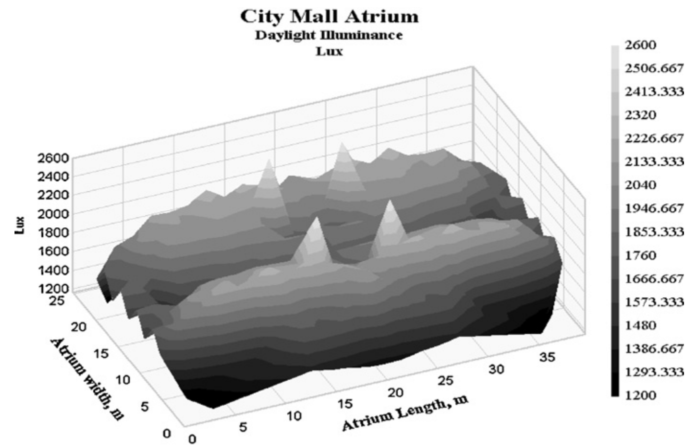


Fig. 7. The 3-dimensional view of dynamic daylight illuminance in CM atrium.

rhythm also decorates the atrium and emphasizes its shape and interrelation, as shown in Fig. 2.

5.1.2. Luminance brightness ratio differences

Continuous variation of luminance brightness ratios is mainly due to daylight variances and contrast between light areas and shadow areas within dynamic shadows rhythm. Luminance brightness ratio differences are seen as dynamic color diversity in the atrium, shown in Fig. 3.

5.1.3. Dynamic reflections

Reflections thrown back from day-lighted atrium surfaces create dynamic effects in the architectural space. Specular reflections increase the sense of atrium spaciousness and dimensions. Dynamic shapes are also drawn on surfaces due to reflections. Dynamic color diversity is related to luminance brightness ratio differences of reflections in the atrium as shown in Fig. 4.

5.2. Questionnaire results and discussion

- Dynamic diversity and variety due to daylight visual aspects is rated in the atrium by the study sample. While the dynamic rhythm of shadows is rated by 86% of the sample as good or more than good for diversity and renewal of vista, daylight variances is rated by 82% of the sample as good or more than good for color diversity and dynamic reflections is rated by 76% of the sample as good or more than good for vista diversity.
- Daylight as an effective architectural design element is rated by 95% of the sample as very good or more than very good. Impact of daylight quality on increasing the esthetic aspects of the architectural space is rated by 95% of sample as very good or even more. Impact of daylight quality on increasing psychological aspects of the architectural space is rated by 89% of the sample as very good or even more, Fig. 5.
- Rating daylight quality in the atrium and rating atrium dynamics caused by visual daylight aspects. While daylight quality in the atrium is rated as good or more by 92% of the sample, atrium dynamics caused by visual daylight aspects is rated by 86% of the sample as good or more.

5.3. Daylight measurements results and discussion

Illuminance was measured in the atrium and is plotted as contour lines shown in Fig. 6. The average illuminance value in atrium is 1825 lux, which is sufficient for atrium activities when comparing it with the recommended illuminance of 200 lux for circulation and public spaces of malls according to lighting design tables. The external illuminance measurement is 10,000 lux [17].

Measurements of daylight illuminance vary according to time and location of measured points from the skylight. The 3-dimentional dynamic view of measured illuminance in atrium is shown in Fig. 7.

6. Conclusion

The study concludes that daylight quality aspects activate the dynamics of architectural space. The study proves that daylight quality is an effective design element for enhancing esthetical and psychological aspects of the architectural space enriching the experience of diversity, interest and pleasure. Elaborating effects of daylight quality on the dynamic of architectural space are toned to daylight quantity design and agrees with it.

The study recommends the following:

1. Adopting daylight for illuminating buildings as a comprehensive qualitative and quantitative design solution to provide required daylight quantities while enhancing architectural space dynamics.
2. Future studies to elaborate daylight quality design methodology and steps directing daylight quality aspects for enriching diversity, variety and dynamics of architectural space.
3. Introduce the knowledge of daylight quality and methods of designing it within courses of teaching architecture.

References

[1] Johnsen K, Dubois M, Grau K. Assessment of daylight quality in simple rooms. Danish Building Research Institute; 2006. Available from: http://www.thedaylightsite.com./ [accessed 1.10.09].
[2] Parpairi K. daylight perception. In: Steane M, Steemers K, editors. Environmental diversity in architecture. 1st ed. New York: Taylor & Francis; 2004.
[3] Osterhaus W. Common language and descriptors required to achieve high quality daylight in buildings. In: The VELUX daylight symposiums in Budapest. 2005. Available from: http://www.thedaylightsite.com./ [accessed 20.09.09].
[4] Dubois C, Demers C, Potvin A. The influence of daylighting on occupants; comfort and diversity of luminous ambiences in architecture. In: Proceedings of national solar 2007 conference. Ohio: American Solar Energy Society; 2007. Available from: http://www.grap.arc.ulaval.ca/ [accessed 20.09.09].
[5] Fontoynont M. Daylight performance of buildings. 1st ed. UK: James & James; 1999.
[6] Boyce P, Hunter C, Howlett O. The benefits of daylight through windows. New York: Lighting Research Center, Rensselaer Polytechnic Institute; 2003. Available from: http://www.usp.br/fau./ [accessed 20 September].
[7] Choi J, Beltran L. Study of the relationship between patients' recovery and indoor daylight environment of patient rooms in healthcare facilities. In: Proceedings of 2004 ISES Asia-Pacific conference. Korean Federation of Science and Technology Societies; 2004. Available from: http://archone.tamu.edu./ [accessed 1.10.09].

[8] Nicklas M, Bailey G. Analysis of the performance of students in Daylit schools; 1996. Available from: http://www.innovativedesign.net [accessed 20.09.09].
[9] HESCHONG MAHONE GROUP. Daylighting in schools: an investigation into relationship between daylighting and human performance. The Pacific Gas and Electric Company; 1999. Available from: http://www.h-m-g.com/ [accessed 1.10.09].
[10] Ander GD. Daylighting performance and design. second ed. USA: John Wiley and Sons; 2003.
[11] HESCHONG MAHONE GROUP. Skylighting and retail sales: an investigation into the relationship between daylighting & human performance. Pacific Gas and Electric Company; 1999. Available from: http://www.h-m-g.com./ [accessed 1.10.09].
[12] Hammad RNS. Technologies of daylighting and artificial lighting. 1st ed. Jordan: Funoon Book Store; 2006 [in Arabic].
[13] Phillips D. Daylighting: natural light in architecture. 1st ed. Italy: Architectural Press an Imprint of Elsevier; 2004.
[14] Koster H. Dynamic daylighting architecture. 1st ed. Switzerland: Birkhauser; 2004.
[15] Michel L. Light the shape of space. 1st ed. USA: John Wiley & Sons Inc.; 1996.
[16] Arnheim R. Art and visual perception. expanded and revised ed. of original 1954 publication USA: The Regents of University of California; 1974.
[17] Hammad RNS. Daylighting and artificial lighting in architecture. 1st ed. Jordan: Arabic Students' Services Center; 1996 [in Arabic].
[18] Hourani MM. Architectural design of commercial malls concentrating on dynamic quality of daylight. Unpublished thesis of M.Sc. degree in architectural engineering, Jordan University, Amman, Jordan; 2010.